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Progress Report

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"Cortical Adaptive Filtering in Bioacoustic Signal Classification"

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Introduction

The optimal use of sonar requires the correct classification of acoustic signals. However, there are several fundamental problems which continue to resist solution including (a) high levels of noise, (b) similarity of the target and non-target signals, (c) interference in performance by situational or contextual factors, and (d) the complexity of the spectral/temporal structure of many signals of interest. Our approach is to understand existing neurobiological solutions to acoustic signal classification and to provide both empirical and computational foundations upon which successful algorithms can be devised and applied to signal classification. A very high degree of acoustic signal classification has been achieved in the auditory systems of many animals. Of particular importance is the *adaptive filtering of acoustic signals at the auditory cortex.* We have discovered that the auditory cortex is rapidly *"retuned"* during training; the receptive fields (RFs) of cortical neurons are altered to favor the acoustic frequency used as a signal of reinforcement.

The *specific objectives* of this project are to determine the extent to which training-induced adaptive filtering (AF) in the auditory cortex can solve the major problems which must be solved for achieving optimum signal classification. Specifically, we will (a) perform quantitative and analytic neurophysiological-behavioral experiments and (b) develop testable computational models (with R. Granger) that will characterize adaptive filtering in the auditory cortex with respect to:

(a) its ability to counteract the deleterious effects of acoustic noise,
(b) the extent to which it can facilitate the discrimination of target signals from similar, non-target signals,
(c) gating adaptive filtering by contextual factors,
(d) its applicability to complex acoustic signals, and
(e) its allocation across the frequency representation in the auditory cortex.

Progress During Initial Phase of the Project

Adaptive Filtering at Inputs to the Auditory Cortex

Basic essential analyses of the adaptive filtering properties of inputs to the auditory cortex (ACx) were completed. Because the primary ACx receives convergent input from both the ventral (MGv) and medial (MGm) medial geniculate body, the receptive fields (RF) of neurons in both nuclei were determined before and after training. MGv cells develop adaptive filtering, increased response to the training frequency (CS), decreased response to the pre-training best frequency (BF), only if they are very similar (within 1/8th octave); this AF is transient and dissipates within one hour. These findings support the role of the MGv as a high-fidelity, frequency-selective input to the ACx and not as an important substrate for AF (Edeline and Weinberger, in press). In contrast, cells in the MGm develop AF regardless of the degree of frequency similarity of the training and best

frequencies and maintain AF for as long as recordings were obtained. These findings support the role of the MGm as a gating mechanism that is an important part of the substrate of AF as fully expressed in the ACx. A comparison of the parameters of AF in the MGm and ACx showed that the former could not fully account for the latter, supporting an active role of the ACx in AF which develops at the highest level of the auditory system (Edeline and Weinberger, submitted).

Adaptive Filtering and Frequency Discrimination

New studies whose focus is to develop an accurate computational model of AF in the ACx were initiated in collaboration with Professor Richard Granger of UCI. Following detailed planning and as an extension of the work of Granger and Lynch on the olfactory cortex and the research plans forwarded by Dr. Granger and myself in September 1990, we agreed to first attack the fundamental problem of how the auditory cortex achieves the discrimination of target from similar non-target signals.

The first task has been to develop an extensive data base that can serve as the basic for the computational work. This first task is well underway. Subjects are trained in a two tone discrimination task that requires absolute identification. We have been able to obtain satisfactory behavioral discrimination within a single recording session, using classical discriminative training procedures, which permits continual recordings from single neurons in the auditory cortex.

A large data base is necessary to characterize discriminative AF across several parameters so that (1) the data cover the range of frequencies and difficulty of discriminations which must be accounted for in a reverse engineering application of the neurobiological findings and (2) the computational work is adequately constrained by actual neuronal data.

These parameters include:

(a) having RFs that cover the frequency range of the auditory cortex at various degree of frequency-specificity (bandwidth), for various types of RA (tuned mainly to one vs. more than one frequency) across the entire sample of cells studied (i.e., approximately 0.1 to 45.0 for the best frequency),
(b) various frequencies for the best frequency
(c) various frequencies for the training frequencies
(d) having various degree of similarity between the training frequencies (i.e., octave frequency distances of 0.0625 to 3 octaves),
(e) and determination of AF properties across the intensity domain.

As emphasized in the detailed proposal, the entire response areas (RA) must be determined in order that an accurate computational model can be developed. In a typical experiment, this involves determining neuronal responses at several pre and post training intervals for intensities from about 0-80 db SPL at 10-30 different frequencies. The data analysis task is very great, but is proceeding smoothly.

To date, 39 behavioral-neurophysiological sessions have been run successfully and this effort is continuing. The octave distance between the two discriminated training frequencies has ranged from 0.15 to 1.0 octaves (mean = 0.573). Behavioral discrimination, evident by differential cardiac response to the CS+ and CS- frequencies, shows adequate discrimination at all octave distances with more difficult discriminations occurring with smaller octave differences, regardless of the absolute frequencies of the two stimuli (regression = 0.395, behavioral discrimination index vs. octave distance).

The attached figure provides a sample of neuronal data obtained in one such discrimination experiment. The data are shown in preliminary three dimensional graphs which depict neuronal discharge rate as a function of frequency and intensity for three periods: *Pre* -- immediately preceding training, consisting of 30 trials each of reinforced (CS+) and non-reinforced (CS-) trials; *Post* -- immediately following training, in which the CS+ was 22.0 kHz and the CS- was 39.0 kHz; *One Hour Post* -- one hour later.

In terms of the parameters listed above, this cell

(a) is a high frequency, multipeaked cell,
(b) with a BF of 27.0 kHz,
(c) training frequencies of 22.0 (+) and 39.0 kHz (-), and
(d) an octave distance between the CS+ and CS- of 0.77 octaves.

Note that ***Pre-training***, the response area was multi-peaked, not uncommon in the auditory cortex of waking, behaving subjects. The best frequency was 27.0 kHz, the CS+ was selected to have a weaker response than neighboring frequencies (e.g., 19.0 and 25.0 kHz) and the CS- was at a minor peak in the response area.

Post-training, it is clear that major changes have developed in the response area. First, the response at the pre-training BF (27.0 kHz) is greatly reduced compared to responses to other frequencies. Second, the response to the CS+ is greatly increased, so much so that it is either the new BF or "tied" with the peak at 31.0 kHz, a former minor peak that is now prominent. Third, the response to the CS- has disappeared completely. Overall, the RA, particularly at the highest intensity, has changed from having several peaks to having two, one of which is at the CS frequency.

One Hour Post-training, additional changes are evident. The RA now has *one peak which is much larger than any others, and that is at the frequency of the CS+*. Its "contender" at 31.0 kHz (see Post-training) is greatly reduced. We have discovered this type of continued, systematic development and sharpening of receptive field plasticity following training in the absence of any additional exposure to any tones, in previous studies of both habituation and simple non-discrimination training for the auditory cortex. Thus, the singular necessity of including so-called "retention" tests in the study of AF plasticity is underscored once again.

In summary, *not only has this neuron discriminated between the CS+ and the CS-, but it has changed from a multiple-frequency tuned cell to a*

single frequency tuned neuron and it is tuned precisely to the frequency of the most important signal.

Plans

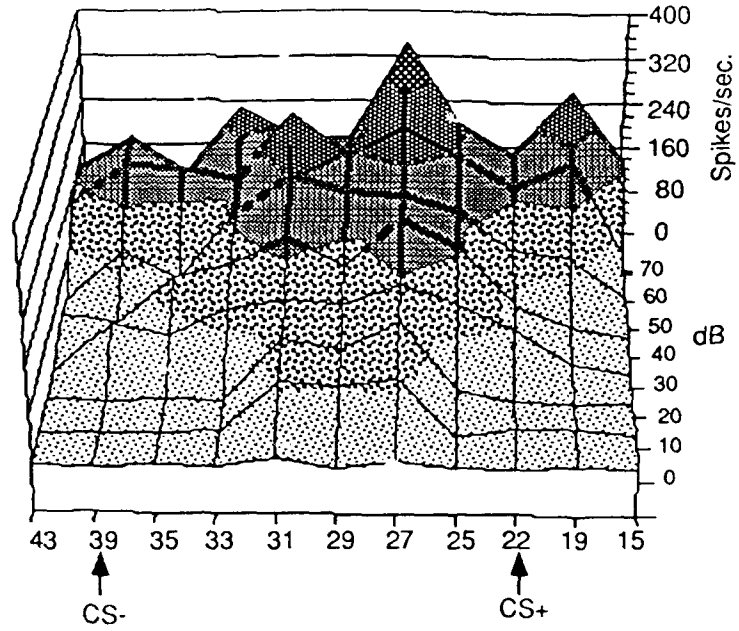
Dr. Granger and I will continue to work closely together to provide the appropriate data necessary for the computational part of this project. At this point, progress depends upon providing a sufficient data base which emerges from a very heavy load for the processing of neurophysiological and behavioral data. Even so, we plan to expand studies to record simultaneously from several neurons and several loci simultaneously. Such within-subject data will certainly facilitate determining the boundary conditions for adaptive filtering. For example, preliminary findings suggest that there needs to be a minimum level of excitatory drive at the training frequencies for adaptive filtering to operate fully on the neuron in question. Dr. Granger and I expect to be able to enter the second stage of the project in which computational work will be possible. We are also exploring the use of stimuli more complex than single tones (e.g., simultaneous tones) to "tax" the cortex in discriminating between acoustic stimuli which have similar tone-interval relationships. As emphasized in our prior documents, reverse engineering for the solution of pressing bioacoustic signal classification problems must be able to deal effectively with stimuli that are considerably more complex than isolated pure tones.

Publications Supported by this Project

Edeline, N.M. and Weinberger, N.M. (1991) Thalamic short - term plasticity in the auditory system: Associative retuning of receptive fields in the ventral medial geniculate body. *Behavioral Neuroscience*, In press.

Edeline, J-M. and Weinberger, N.M. Associative retuning in the thalamic source of input to the amygdala and auditory cortex; Receptive field plasticity in the medial division of the medial geniculate body. Submitted.

Pre



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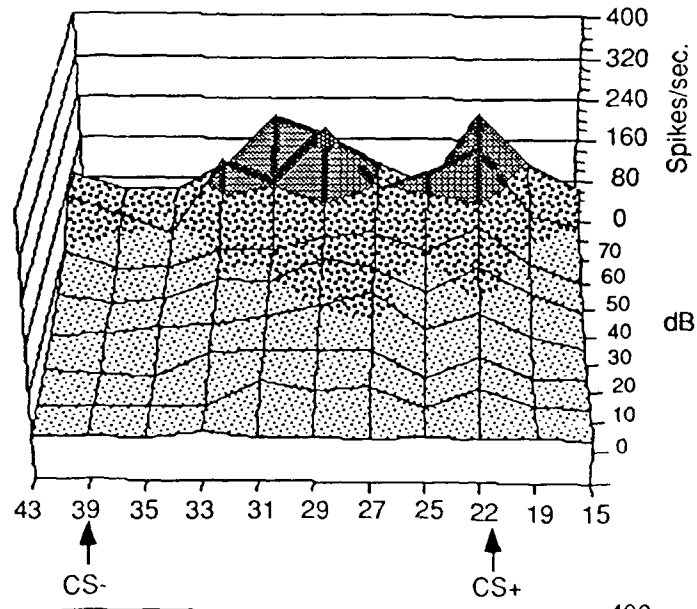
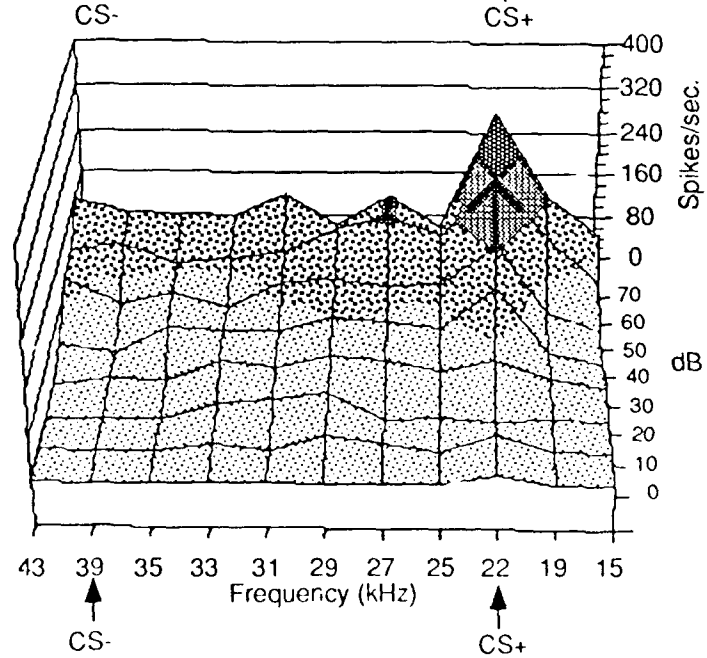


One Hour Post



N.M. Weinberger
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